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Letter to the Editor

The dependence of perceived speed upon signal intensity

In a recent paper, Edwards and Grainger (2006) manipulated the coherence of random dot patterns and found that a reduction in coherence led to an increase in perceived speed; they took this to indicate that vector averaging is not employed in global speed calculations (Edwards & Grainger, 2006). We would like to take this opportunity to comment on the generality of their findings.

As Edwards and Grainger note, the relationship between coherence and perceived speed has previously been studied (Zanker & Braddick, 1999). The latter found no effect of coherence on perceived speed. However, Zanker and Braddick used random re-plotting of noise dots, whereas, Edwards and Grainger used a random walk stimulus (Scase, Braddick, & Raymond, 1996). In the case of the Zanker and Braddick study the result is unsurprising, subjects were simply effective at separating signal from noise. However, in the light of the following studies, the results of Edwards and Grainger study *are* surprising.

As part of a conference presentation we presented data which robustly indicated a *reduction* of perceived speed with a reduction of coherence (Benton & Curran, 2004). These data, and the method of their collection, are presented here as Supplementary Material. Our results showed a strong linear relationship between coherence and speed such as would be predicted if vector averaging formed a component of our speed judgements in patterns of this type. Additionally, a similar result has also previously been reported (Freeman & Sumnall, 2002)—as can be seen from Fig. 2 in their paper, these authors again found a linear decrease in perceived speed with decreases in coherence.

The Benton and Curran (B&C), Freeman and Sumnall (F&S) and Edwards and Grainger (E&G) studies all used similar types of RDK—random walk with allocation to noise or signal for each dot on each frame. The RDK parameters that one might think critical for motion integration are dot speed, dot density and update rate. The E&G findings (and their subsequent conclusions) are based on a single point within this parameter space (6.7 deg/s, 1.3 dots/deg^2, 20 Hz). The other studies looked at a wider range of dot speeds (B&C: 1, 2, 4, 8 and 16 deg/s; F&S: 2.83, 5.66 and 11.31 deg/s), used markedly different dot densities from one another (B&C 63 dots/deg^2; F&S 1.5 dots/deg^2) and employed slightly different update rates (B&C: 80 Hz; F&S 100 Hz). Given their findings, it is reasonable to conclude that the Edwards and Grainger result is not the general result. In contrast, it appears that reductions of coherence *generally* lead to linear reductions in perceived speed such as would be found if vector averaging formed an intrinsic part of our speed calculations (Watamaniuk & Duchon, 1992).

E&G explain their result by proposing that perceived speed is influenced by the relative motion in the stimulus. They note that relative speed has previously been shown to influence speed judgements in dot displays containing opposite motions organised either to produce transparency or kinetic boundaries (De Bruyn & Orban, 1999). E&G extend this finding by showing that increasing the angle between transparent dot planes leads to increases in their perceived speeds. The finding that perceived speed may be influenced by relative motion is (rather obviously) dependent upon the fact of there being two separate motions to compare. If relative motion is a factor in E&G's coherence/speed results, this can readily be tied to the relative motion findings by proposing some degree of motion segregation in E&G's displays.

As noted above, the studies of B&C and F&S show a very different pattern of results; one that is consistent with a strong influence of integration (and thus vector averaging) rather than motion segregation. If E&G's relative motion account is correct, then some difference between their study and those of B&C and F&S must be responsible for a shift in behaviour away from relative motion judgements towards something that looks very much like motion integration. In terms of critical stimulus parameters, the F&S and E&G studies use similar dot densities and share a similar speed. The important difference would therefore appear to be the update rate (E&G 20 Hz, F&S 100 Hz).

On the basis of these observations we can reasonably ask the following two connected questions. (1) Can motion segmentation, and the subsequent incorporation of relative motion into perceived speed, reasonably account for E&G's findings? (2) Can the difference in frame rate between the E&G and F&S studies lead to a difference in segmentation behaviour such that the motion of the stimuli may be integrated rather than segmented? Let us start with the reasonable assumption that motion segmentation operates over some temporal window; the difficulty then is to estimate how long that temporal window might be. If segmentation works through the analysis of MT population response then segmentation's temporal window may be as little as 20 ms, the shortest integration time found for cells in that region (Bair & Movshon, 2004). Another more reasonable estimate might be the time needed to detect transparency, roughly somewhat less than 100 ms (Curran, Hibbard, & Johnston, 2007), although performance (and therefore integration) presumably asymptotes at some higher value than this. Alternatively, temporal integration measured with direction discrimination in RDKs may provide a better metric—this would predict an integration window on the order of some 500 ms (Watamaniuk & Sekuler, 1992).

Clearly, at higher frame rates, more frames fall within the putative segmentation temporal window. If we assume, purely for the sake of exposition, that this window is 200 ms long, then only four frames would be integrated in the E&G stimulus whilst 20 frames of the F&S stimulus would be integrated. Such differences in sampling will inevitably lead to differences in the patterns of local velocities present after this temporally integrative process is applied. We roughly simulated these differences by taking 100,000 dots and then moving them at 1 pixel per frame with various coherences and for various numbers of frames (note that our notional dot positions were not restricted to integer values). Fig. 1

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shows histograms of the normalised distances moved by the dots along the direction of coherent motion. Both lowering the number of frames and raising the coherence lead to increased bimodality. Therefore, integrating over only a small number of frames will result in a bimodal distribution of dot velocities which may well easily be segregable. In contrast higher numbers of frames clearly

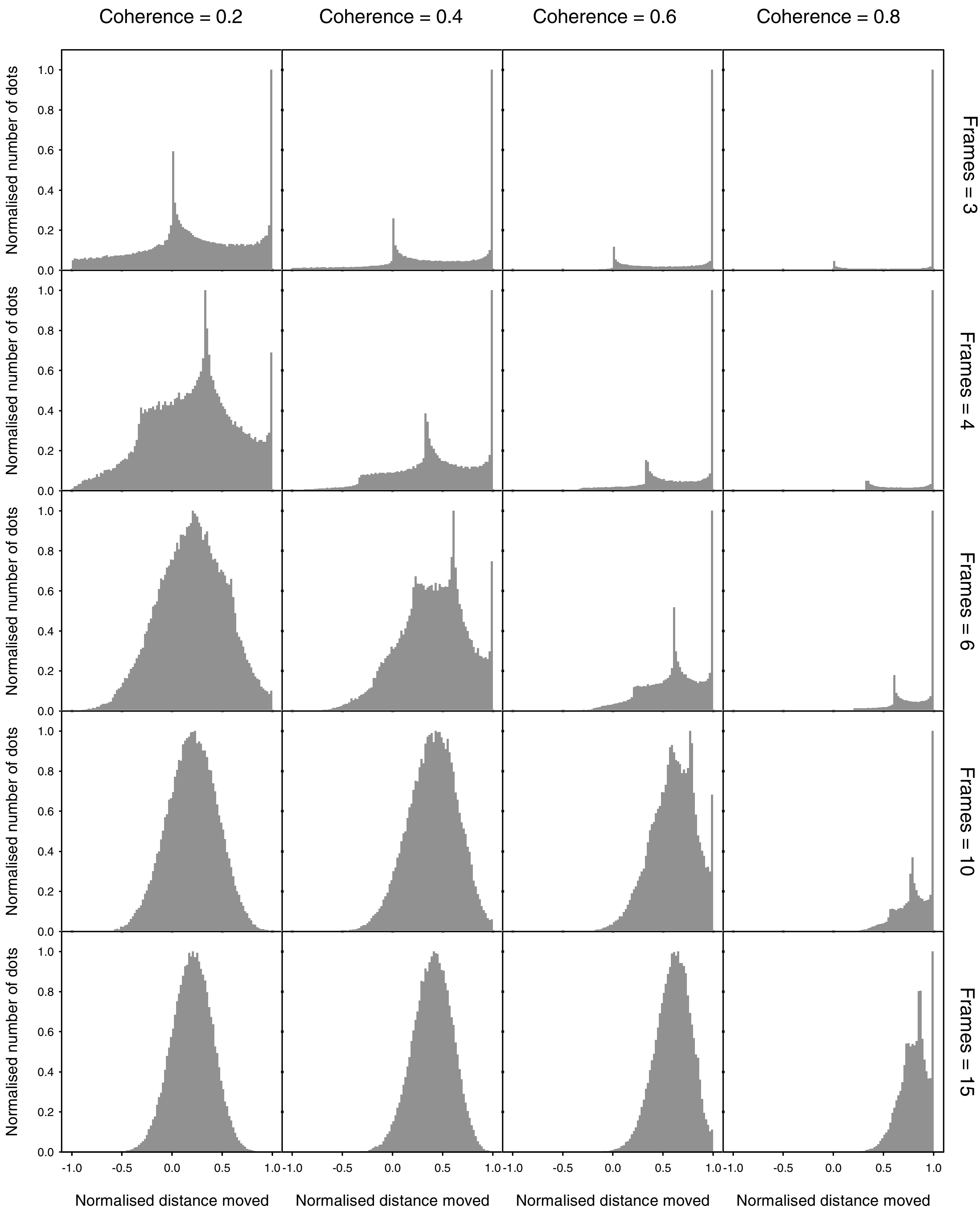

Fig. 1. Histograms showing the number of dots moving various distances along the direction of coherent motion. Note that all two dimensional distance-moved vectors were projected onto the direction of coherent motion. Each histogram consists of 100 bins evenly sampling the range of possible distances moved.

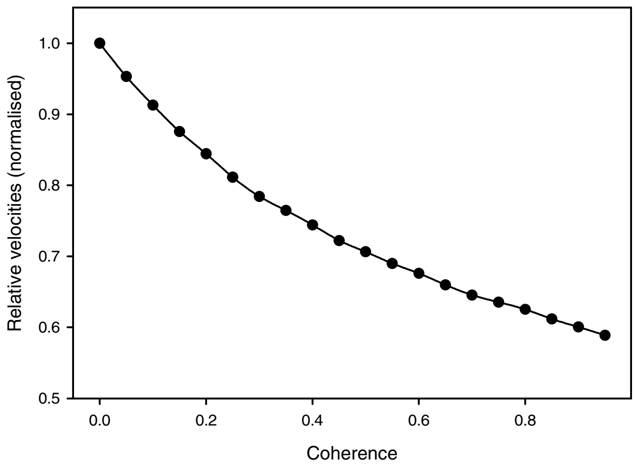

Fig. 2. Relative speed between those dots falling into the fastest bin and the vector average of those that do not, plotted as a function of RDK coherence.

result in a unimodal distribution which is presumably more likely to give rise to a single unified percept of global motion. Therefore, a change in the frame rate used (and therefore the number of frames integrated over) might reasonably account for a shift from segregative to integrative behaviour.

In answer to the question of whether relative speed can account for an increase in speed with a decrease in coherence, the answer is clearly "yes" as can be seen in Fig. 2. Here, we take the difference in speed between those dots falling into the fastest bin and the vector average of those that do not. The fastest dots are those that move coherently over their four frames—one can well imagine that these may be easy to segregate from the other dots which consequently form the background.

That the number of frames integrated over can make a substantial difference to the subsequent distribution of velocities is an inescapable fact. Furthermore, an estimate of 300 ms or less for segmentation's temporal window is firmly within the bounds of possibility. Such a value may produce unimodal distributions when a 100 Hz update rate is used (F&S) and bimodal distributions when a 20 Hz update rate is used (E&G). Motion segregation based on the latter, and the subsequent influence of relative velocity can, as E&G propose, readily account for their inverse relationship between coherence and perceived speed. If, as seems entirely possible, a shift from bimodality to unimodality drives an increased tendency for motion integration, then the difference in patterns of results between E&G's study and those of B&C and F&S may be accounted for.

The only difficulty with the account given above is the finding noted by E&G that patterns with zero coherence appear to move fastest—of course, at zero coherence the distribution of velocities is unimodal. One might reasonably argue that the strength of global motion is determined by the coherence and that in a zero coherence pattern there is no global motion component. It may well be the case that, when asked to make a speed comparison, subjects attempt to carry out the task by basing their judgements on the only point of commonality between the two motions, the local velocities present in each. Any pair of dots taken randomly from a zero coherence pattern will, on average, have more relative velocity than those taken from a coherent pattern. Of course such a mechanism might underlie all of E&G's results and the switch from local relative motion to integrated global motion may occur as velocity distributions become more unimodal and consequently more readily interpreted as a globally moving whole.

In conclusion, the result of Edwards and Grainger does not generalise—other researchers have robustly demonstrated that perceived speed increases as RDK coherence increases. The key difference between the various studies appears to be their update rates; with higher update rates one tends to find that increases in coherence lead to increases in perceived speed. In contrast Edwards and Grainger found the opposite pattern of results; they appeal to relative motion as the possible causal agent underlying their finding. Clearly in order to have relative motion you need two separable entities to compare with one another. In other words the appeal to relative motion implicitly accepts the possibility of motion segregation. This in turn must surely compromise any general conclusions that Edwards and Grainger draw about the processes of motion integration. Our results have clear implications for researchers using RDKs to probe suprathreshold motion integration; in general it is best to err on the side of caution and choose higher update rates and lower coherences where possible.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.visres.2008.10.017.

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